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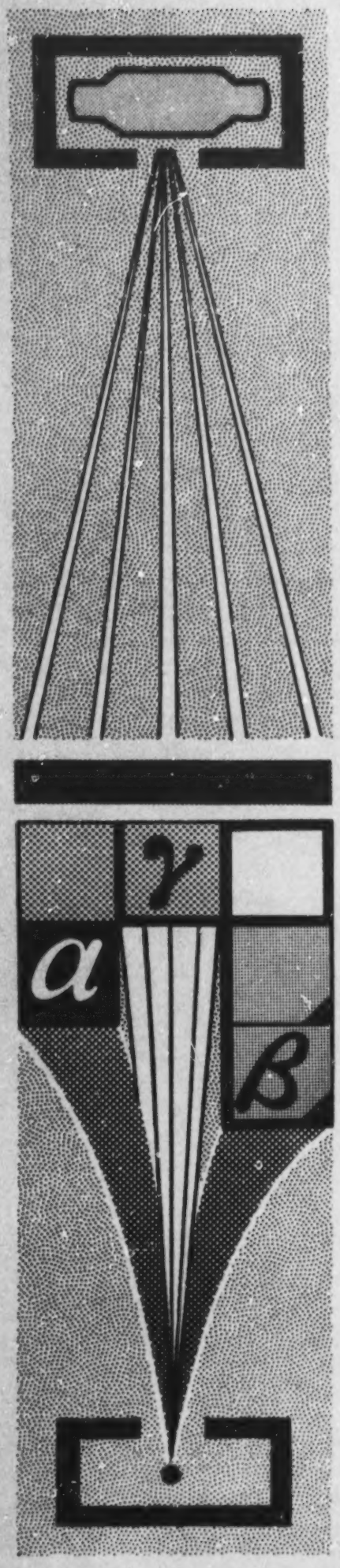


# RECOMMENDATIONS for the SAFE OPERATION of PARTICLE ACCELERATORS

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service
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# RECOMMENDATIONS for the SAFE OPERATION of PARTICLE ACCELERATORS

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## FOREWORD

The trend in particle accelerators is toward smaller machines that produce high-intensity radiation. These accelerators are finding a wide application in activation analysis, physics, radiography, crosslinking of polymers, medical therapy, and isotope production. For many of these machines there is a lack of generally accepted radiation safety procedures. This report is the culmination of a project to develop a set of basic recommendations for the safe operation of particle accelerators.

These recommendations are intended for the use of particle accelerator operators, administrators, and State radiological health personnel. They should be considered as the minimum safety procedures for accelerator facilities, and are intended to supplement existing regulations or standards and to emphasize the more important items in an accelerator radiation safety program.

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CONTENTS


| | Page |
|---|---|
| INTRODUCTION | 1 |
| SCOPE | 1 |
| RECOMMENDATIONS FOR THE SAFE OPERATION OF PARTICLE ACCELERATORS | 2 |
| Administration and Personnel | 2 |
| Accelerator Controls | 2 |
| Interlock Systems | 2 |
| Warning Devices | 3 |
| Radiation Monitoring | 3 |
| Radiation Protection Survey | 4 |
| DISCUSSION | 4 |
| REFERENCES | 5 |
| APPENDIX A - DEFINITIONS | 6 |
| APPENDIX B - SUMMARY OF PUBLISHED ACCELERATOR ACCIDENTS INVOLVING RADIATION EXPOSURE | 7 |

## INTRODUCTION

The Radioactive Materials Section has for some time been investigating the radiation hazards associated with particle accelerators. Efforts have been made to: 1) determine the extent of accelerator use in medicine, research, and industry, 2) evaluate the occupational radiation hazards presented by such equipment, and 3) investigate monitoring techniques, survey equipment and dosimetry around such accelerators. This has been accomplished through both "in-house" activities (1-3) and work performed by contractors (4).

These investigations revealed an apparent lack of generally accepted safety procedures for particle accelerator facilities. Thus, in October 1967, a list of interim recommendations for the safe operation of particle accelerators was drafted and distributed within the NCRH for comment. A revised list was then sent to State health departments, other radiological health personnel, and accelerator users for their review. These comments and suggestions were evaluated in January 1968, and where feasible, were incorporated into the list as it now appears. This report has been prepared to disseminate the recommendations rapidly and to provide a basis for further discussion in the continuing evaluation of safety guidelines.

Terms used in the recommendations, such as radiation protection supervisor, qualified expert, and interlocks, have the same definition as those found in National Bureau of Standards (NBS) handbooks and other references. (See Appendix A)

Appendix B summarizes information on previous known accelerator accidents which have been reported in the literature.

## SCOPE

The term "particle accelerator" is very broad and obviously covers many types of devices. It is generally defined as a device used to impart kinetic energy to electrically charged particles such as electrons, protons, deuterons, and helium ions. The recommendations that follow refer to devices that accelerate particles to energies greater than approximately 1 MeV, with the exception that they also apply to neutron generators which operate with a potential of about 150 kV. Such accelerators as cyclotrons, betatrons, linear accelerators, Van de Graaff accelerators, Cockcroft-Walton type neutron generators, and resonant transformers are included.

The recommendations should be considered as the basic or minimum safety procedures for all such accelerator facilities. Amplification of any and all items as they apply to a specific facility is encouraged. The intention here is to supplement existing regulations or standards (5-11) and to emphasize the more important items in an accelerator radiation safety program. Individuals should refer to and be familiar with State and/or federal regulations and standards regarding exposure to ionizing radiation, accelerator shielding, and other applicable radiological health considerations.

## RECOMMENDATIONS FOR THE SAFE OPERATION OF PARTICLE ACCELERATORS

### Administration and Personnel

1. A responsible administrator for the particle accelerator facility shall appoint a radiation protection supervisor and, if appropriate, a radiation safety committee.

2. The accelerator facility shall be under the guidance of the radiation protection supervisor who shall be responsible for advising on radiation safety at the accelerator.

3. The operator of the accelerator shall be responsible for all operations connected with the accelerator, including radiation safety. The radiation protection supervisor shall have the authority to cease operations at the facility because of radiation safety considerations.

4. No individual shall be permitted to act as an operator of an accelerator until such person has: 1) received an acceptable amount of training in radiation safety as approved by the radiation protection supervisor; 2) demonstrated competence to use the accelerator, related equipment, and radiation survey instruments which will be employed; and 3) been approved by the radiation protection supervisor.

5. Written operating and emergency procedures pertaining to radiation safety shall be established for each accelerator facility by a qualified expert, and approved by the radiation protection supervisor.

6. Operators and other appropriate personnel shall be familiar with and be given a copy of the written operating and emergency procedures pertaining to radiation safety. Such procedures should be posted near the accelerator control console.

### Accelerator Controls

7. Particle accelerators shall be secured when not in operation to prevent unauthorized use.

8. Meters and controls on the accelerator control console shall be clearly identified and easily discernible.

### Interlock Systems

9. All entrances into a target room or other high radiation area shall be provided with interlocks.

10. Only a switch on the accelerator control console shall be used to turn the accelerator beam on and off. The safety interlock system shall not be used to turn off the accelerator beam, except in an emergency. If the interlock system does turn off the accelerator, it shall not be possible to resume operation without resetting the accelerator "ON" switch at the control console.

11. All safety interlocks shall not be dependent upon the operation of a single circuit.

12. A scram button or other emergency power cut-off switch shall be located and easily identifiable in all high radiation areas. Such a cut-off switch shall include a manual reset, so that the accelerator cannot be restarted from the accelerator control console without resetting the cut-off switch.

13. Electrical circuit diagrams of the accelerator and the associated interlock systems shall be kept current and on file at each accelerator facility.

Warning Devices

14. All locations designated as high radiation areas, and entrances to such locations shall be equipped with easily observable flashing or rotating red or magenta warning lights that operate automatically when, and only when, radiation is being produced. Lights of a different color shall be used when other visual indicators are required.

15. All safety and warning devices, including interlocks, shall be checked at intervals not to exceed six months to determine that they are functioning properly, and appropriately serviced.

Radiation Monitoring

16. Appropriate portable radiation monitoring equipment shall be available at the accelerator facility, properly maintained and calibrated, and sensitive to those radiations being monitored.

17. An appropriate radiation m nitor shall be used within an accelerator target room and other high radiation areas. This may be: 1) an area monitor with an easily observable indicator that warns of radiation levels above a predetermined limit in accessible areas; and/or 2) a personal radiation monitor of the "chirpie" type carried into the room; and/or 3) a portable survey instrument carried into the room.

18. Personal radiation dosimeters that measure the expected radiations and are of sufficient range to be useful under normal and accident conditions shall be worn by all persons designated by the radiation protection supervisor.

Radiation Protection Survey

19. Before a new installation is placed in routine operation, a radiation protection survey shall be made by a qualified expert.

20. A radiation protection survey shall be performed when changes have been made in shielding, operation, equipment, or occupancy of adjacent areas, and periodically to check for unknown changes and malfunctioning equipment.

21. Records of all radiation protection surveys, inspections, and maintenance performed on the accelerator and related components shall be kept current and on file at each accelerator facility, and periodically reviewed by the radiation protection supervisor.

## DISCUSSION

The following comments, many of which were made by the reviewers of the draft recommendations, will give some additional background into the writing of the recommendations and will indicate the limitations of the list.

While the need for a radiation protection supervisor is clearly apparent, the need for a radiation safety committee at every particle accelerator facility depends upon the actual use of the accelerator. If an accelerator is to be used for a single purpose under the same irradiation conditions and for a limited number of hours per week, a radiation safety committee may not be appropriate. However, if an accelerator receives heavy use under varying conditions by many groups within an organization, a radiation safety committee should be mandatory. Between these two extremes the decision to have a committee must be based upon the professional judgment of the radiation protection supervisor and the management of the facility.

Throughout the recommendations there is no mention of maximum permissible exposures to radiation since it is felt that the reader should be familiar with applicable State or federal regulations on this subject. Similarly, there is no mention of accelerator shielding or target handling, which are beyond the scope and intent of these recommendations.

Consideration should be given to having at least two accelerator operators on duty whenever an accelerator is in operation. The primary operator should be responsible for all operations pertaining to the accelerator and an assistant operator should be available for other duties, such as radiation monitoring with a portable detection instrument, answering telephones, etc.

If for any reason, it is necessary to intentionally bypass a safety interlock or interlocks, such action should be: 1) authorized by the accelerator operator or other responsible person, 2) recorded in a maintenance log or other record and posted at the accelerator control console and 3) terminated as soon as possible.

Similarly, another desirable feature of an interlock system might be individual pullout-type plugs that a person entering the target room must remove from a rack and carry with him at all times while in the target room. It would then be necessary to return all plugs to the rack before the accelerator could be started.

It is suggested that all safety interlocks be "fail safe," i.e., designed so that any defect or component failure in the interlock system prevents operation of the accelerator.

## REFERENCES


(1) Boggs, R. F., "Health Physics Aspects of the Operation of Cockroft-Walton Type Neutron Generators," U.S. Department of Health, Education, and Welfare, Public Health Service, March 1966.

(2) Boggs, R. F., Jacobs, R., Leupold, R. L., "Radiological Health Problems Associated with the Operation of Neutron Generators," presented at 11th Annual Meeting of Health Physics Society, Houston, Texas, June 30, 1966.

(3) "KWIC Index and Abstracts for Selected Particle Accelerator and Related Health Physics References," Radioactive Materials Section, MORP, National Center for Radiological Health, January 1968.

(4) Nellis, D. O., Hudspeth, E. L., Morgan, I. L., Boggs, R. F., "Tritium Contamination in Particle Accelerator Operation, U.S. Public Health Service, Environmental Health Series, PHS Publication No. 999-RH-29, November 1967.

(5) "Safety Standard for Non-Medical X-ray and Sealed Gamm-Ray Sources," National Bureau of Standards Handbook 93, July 1, 1964.

(6) "Shielding for High-Energy Electron Accelerator Installations," NCRP Report No. 31, National Bureau of Standards Handbook 97, July 1, 1964.

(7) "Medical X-ray and Gamma-Ray Protection for Energies Up to 10 MeV (Equipment Design and Use)," NCRP Report No. 33, February 1, 1968, National Council on Radiation Protection and Measurements.

(8) "Medical X-ray Protection Up to Three Million Volts," NCRP Report No. 26, National Bureau of Standards Handbook 76, February 9, 1961.

(9) "Code of Practice for the Protection of Persons Exposed to Ionizing Radiations in Research and Teaching," Ministry of Labour, 1964, Her Majesty's Stationery Office, London.

(10) "Measurement of Absorbed Dose of Neutrons, and of Mixtures of Neutrons and Gamma-Rays," NCRP Report No. 25, National Bureau of Standards Handbook 75, February 3, 1961.

(11) "Standards for Protection Against Radiation," 10 CFR 20.202 (6)(3), USAEC.

## APPENDIX A

## DEFINITIONS

High Radiation Area: Any area, accessible to personnel in which there exists radiation at such levels that a major portion of the body could receive in any one hour a dose in excess of 100 millirem. (7)

Interlock: A device for precluding access to a high radiation area by automatically reducing the exposure rate upon entry of personnel. (3)

Qualified expert: A person having the knowledge and training to measure ionizing radiation, to evaluate safety techniques, and to advise regarding radiation protection needs. For example, persons certified in this field by the American Board of Radiology, or the American Board of Health Physics, or those having equivalent qualifications. (3)

Radiation Protection Supervisor: Person directly responsible for radiation protection. It is his duty to insure that all procedures are carried out in compliance with pertinent established rules. (1)

NCRP Report No. 33(3) states further that a radiation protection supervisor (who may be the user himself) shall be designated for every installation to advise on the establishment of safe working conditions according to the recommendations of NCRP Report No. 33 and in compliance with all pertinent federal, State, and local regulations. He should be familiar with the basic principles of radiation protection in order to properly discharge his responsibilities, although for details he may consult with appropriate qualified experts.

APPENDIX B

## ARY OF PUBLISHED ACCELERATOR ACCIDENTS INVOLVING RADIATION EXPOSURE

1. ACCELERATOR TYPE: Medical 1,200 kV Electrostatic Generator
   DATE: December 1, 1944
   LOCATION: Massachusetts General Hospital, Boston, Mass.
   NO. INDIVIDUALS EXPOSED: Six
   EXPOSURE: 1000-2000 "tissue roentgens"
   PRIMARY CAUSE: Lack of appreciation of hazard
   DESCRIPTION OF ACCIDENT:

   The target of an electrostatic generator in a large hospital was removed in order to determine the size and location of the focal spot using a piece of film. It was known that there was a definite danger in exposure to the direct beam but it was thought that it would be safe to stand at a distance of several feet. Consequently, six staff members entered the room while the machine was in operation to observe the fluorescence due to the electron beam. Severe radiodermatitis developed over much of the body areas of the exposed individuals.

   Ref: Robbins, L., et al.; "Superficial 'Burns' of Skin and Eyes from Scattered Cathode Rays;" Radiology, Vol. 46, No. 1, 1946.

2. ACCELERATOR TYPE: Linear Accelerator
   DATE: Not stated
   LOCATION: Some university
   NO. INDIVIDUALS EXPOSED: Two
   EXPOSURE: Not stated
   PRIMARY CAUSES: Failure to follow established operating procedures and target area not completely barricaded
   DESCRIPTION OF ACCIDENT:

   Two research assistants entered the target area of a linear accelerator without notifying the accelerator operator. They also failed to remove an interlock key and ignored warning lights, signs, and the sound of the accelerator klystron pulsers. One worker leaned over, adjusted the target by hand, and when bending over still more to make the alignment by eye, noticed a bluish iridescence in his eyeglasses. Both realized what had happened and left target area immediately. No biological damage was found.

   The target area, which was normally barricaded, was made accessible by construction work. However, each researcher was experienced and familiar

with proper safety precautions.

Ref: Hayes, Daniel F., A Summary of Accidents and Incidents Involving Radiation in Atomic Energy Activities, June, 1945 through December, 1955. TID 5360 pp. 66 (August, 1956).

3. ACCELERATOR TYPE: Linear Accelerator
DATE: Not stated
LOCATION: Some university
NO. INDIVIDUALS EXPOSED: One
EXPOSURE: Not stated
PRIMARY CAUSES: Inadequate indoctrination of worker, exposure area not completely barricaded, and unwarranted assumption by accelerator operator that area was clear of workers.

DESCRIPTION OF ACCIDENT:

A part-time worker, whose job it was to fill vacuum pump traps, ignored warning devices and signs, and climbed across the top of the accelerator shielding into an exposure area. He thus avoided the interlocked gates. The operator, assuming the worker was through with his work, proceeded to warm up the machine and operate it.

The worker was not exposed to the primary beam and no signs of biological damage were found.

Ref: Hayes, Daniel F., A Summary of Accidents and Incidents Involving Radiation in Atomic Energy Activities, June, 1945 through December, 1955. TID 5360, pp. 67 (August, 1956)

4. ACCELERATOR TYPE: Electron Linear Accelerator
DATE: January 6, 1959
LOCATION: Livermore, California
NO. INDIVIDUALS EXPOSED: Seven
EXPOSURE: 41 rem
PRIMARY CAUSE: Reliance on incomplete safety interlock circuits

DESCRIPTION OF ACCIDENT:

A new electron linear accelerator was being operated to accumulate data to enable the engineering section to design permanent equipment for this machine. A number of remote operating circuits were not in operation, including remote controls for the tungsten beam definers, remote radiation monitoring system, and the interlocked barrier to the beam room area. The barrier was temporarily replaced by 4 x 4 ft. plywood and a warning sign.

A series of adjustments were being made on beam defining plates. Radiation surveys were made with negative results when personnel entered the

cell after the first three adjustment runs. No survey was made after the fourth and fifth runs. A survey made after the sixth run showed 1,000 r per hour level.

During all entries to the cell, the key which was designed to lock all controls in the "OFF" position was removed from the control panel.

It was determined that the film badges had been exposed to about 200 keV energy gamma radiation. An exposure dose of 41 r was assigned to physicist A. This dose was received in a period of about one minute, which was the established time he worked alone on plates 3 and 4 and entered the cell to measure very high radiation levels. The next highest reading of 400 mR was received by physicist B. All others received less than 50 mR.

Reliance was placed for safe operation on incomplete safety interlock circuits. Extreme care should be exercised in all situations where it is known that mechanical safety may be incomplete or inoperative.

Ref: A Summary of Industrial Accidents in AEC Facilities, December, 1961. TID 5360 (Suppl. 3-Revised) pp. 8.

5.

| | |
|---|---|
| ACCELERATOR TYPE: | Van de Graaff |
| DATE: | November 8, 1960 |
| LOCATION: | Sandia Corporation, Albuquerque, New Mexico |
| NO. INDIVIDUALS EXPOSED: | Two |
| EXPOSURE: | Electron beam - by indirect measurement using film badge: 760 rads incident dose to face of employee "A;" 53 rads total body dose to employee "B" |
| PRIMARY CAUSE: | Operator failed to check potential radiation source |

DESCRIPTION OF ACCIDENT:

An employee "A," was accidentally exposed to an electron beam emanating from a Van de Graaff accelerator while setting up an experiment in front of the beam tube.

The machine operator, employee "B," put the machine on self-charge with "A's" consent and knowledge, as "A" entered the beam room. This was done to check the self-charge rate and limit of the machine. The term "self-charge" refers to the operation of the belt which places a static charge on the high voltage terminal. The beam current and belt charge (the normal source of electrons) were not turned on. Therefore, there should have been no detectable emission from the beam tube at this time.

"A" proceeded to end of the beam tube and began setting up his experiment. After approximately two minutes, he came out of the beam room, since his

face felt warm. He then went to the washroom and washed his face. "A" asked "B" if there was any residual beam current. The operator stated that the beam current was not on, but that he would check. "B" entered the beam room with a low range survey meter and made a measurement in front of the beam tube. At first he saw no reading, but as he started to leave, the meter pegged at 20 millirems.

"A" received multiple radiation burns in the middle section of the face, abdomen, and both hands. Employee was not wearing his film badge. However, an indirect measurement was made by placing a film badge at the 33 cm distance and exposing it under simulated conditions. Calibration was interpreted as 760 rads incident dose to the face at 33 cm.

"B" received a total body dose of 53 rads as determined by film badge reading.

Ref: (1) Burnett, W. D., Rarrick, H. L. and Tucker, G. E., "Van de Graaff Electron-Beam Exposure at Sandia Corporation" Nuclear Safety, Vol. 4, No. 4, June, 1963, pp. 155.

(2) A Summary of Industrial Accidents in USAEC Facilities, December, 1961. TID 5360 (Supplement 3-Revised), pp. 23.

(3) Bliss, S. P., "Medical Aspects of an Accidental Exposure to Van de Graaff Generator," (In) "Premier Colloque International Sur la Protection Aupres des Grands Accelerateurs," Paris, Presses Universitaires de France, pp. 36-39.

6. ACCELERATOR TYPE: Gradient Synchrotron
DATE: October 17, 1963
LOCATION: Argonne, Illinois
NO. INDIVIDUALS EXPOSED: Two
EXPOSURE: Whole body exposures of 3.8 rem and 2.8 rem
PRIMARY CAUSE: Incorrect Beam Stopper
DESCRIPTION OF INCIDENT:

Employees exposed while making adjustments on a gradient synchrotron. Before the work of adjusting the synchrotron began, a beam stopper was inserted into the synchrotron to prevent exposure to the employees. However, the correct beam stopper was not inserted and the employees carried out their assignment unaware of this.

Ref: A Summary of Industrial Accidents in USEAC Facilities, 1963-1964. TID 5360 (Supplement 5), December, 1965, pp. 22.

7. ACCELERATOR TYPE: Cyclotron
DATE: June, 1964
LOCATION: Berkeley, California
NO. INDIVIDUALS EXPOSED: One
EXPOSURE: 3.4 rem whole-body
PRIMARY CAUSE: Not stated
DESCRIPTION OF INCIDENT:

While removing targets cyclotron bombarded from a vacuum chamber in a high level cave, an employee was exposed to radiation.

Ref: A Summary of Industrial Accidents in USAEC Facilities, 1963-1964. TID 5360 (Supplement 5), December, 1965, pp. 30.

8. ACCELERATOR TYPE: Cyclotron
DATE: January 11, 1965
LOCATION: Berkeley, California
NO. INDIVIDUALS EXPOSED: One
EXPOSURE: Estimated quarterly external whole-body exposure 3.6 rems
PRIMARY CAUSE: Not stated
DESCRIPTION OF ACCIDENT:

While an accelerator technician was preparing for an experiment in the area of a cyclotron, he received a whole-body exposure.

Ref: Nuclear Safety, Vol. 7, No. 4, Summer 1966, pp. 496.

9. ACCELERATOR TYPE: Linear Accelerator
DATE: February 18, 1965
LOCATION: Rockford, Illinois
NO. INDIVIDUALS EXPOSED: One
EXPOSURE: Interior of body - 0.2 to 5 rad
Right hand - 42,000-240,000 rad
Right foot - 300-29,000 rad
PRIMARY CAUSES: Failure to follow established operating procedures and insufficient barricade of accelerator room
DESCRIPTION OF ACCIDENT:

An industrial worker was accidentally exposed to an electron beam when he walked into a room to place an octagonal mold on a conveyor belt near the output port of an operational accelerator.

The accelerator was mounted so that 10.8 MeV electrons were directed downward after emerging into the air from a vacuum chamber at a height of 75 cm from the floor. The electron beam spread rapidly in its downward course due to its intrinsic angular distribution coupled with multiple scattering in the window and air. At 46 cm above the floor it struck a conveyor belt whose function it was to carry industrial products

through the beam. The conveyor system occupied part of the entryway to the accelerator room. In order to accommodate this conveyor system the bottom of the door, guarding the entryway, had been sawed off. The worker gained entrance to the accelerator room through the resulting gap without tripping the electrical interlocks. After the accident, the door was redesigned to accommodate the conveyor system without leaving a gap.

Exposure resulted in double amputation 5-6 months later.

Ref: Lanzl, L. and Rozenfeld, M., "Injury Due to Accidental High-Dose Exposure to 10 MeV Electrons," Health Physics Vol. 13, No. 3 (1967),pp. 241-251.

10. ACCELERATOR TYPE: Van de Graaff
DATE: May 22, 1956
LOCATION: Oak Ridge, Tennessee
NO. INDIVIDUALS EXPOSED: One
EXPOSURE: Estimated hand (finger) exposure 51 rem
PRIMARY CAUSE: Beam shutter failure
DESCRIPTION OF ACCIDENT:

A physicist received an exposure when the beam shutter of a Van de Graaff machine opened inadvertently while he was in target room making adjustments on experimental apparatus.

Ref: Nuclear Safety, Vol. 7, No. 4, pp. 497.

11. ACCELERATOR TYPE: Not stated
DATE: 1966
LOCATION: Not stated
NO. INDIVIDUALS EXPOSED: One
EXPOSURE: 300 rem to one foot
PRIMARY CAUSE: Not stated
DESCRIPTION OF INCIDENT:

A technician was exposed to an estimated 300 rem of X-ray to one foot in an accelerator incident.

Ref: Annual Report to Congress of Atomic Energy Commission for 1966; January 1967, pp. 350.

12. ACCELERATOR TYPE: 3 MeV Van de Graaff
DATE: October 4, 1967
LOCATION: Harmarville, Pennsylvania
NO. INDIVIDUALS EXPOSED: Three
EXPOSURE: Two men 500-600 rem whole body.
Third man 100-200 rem whole body.
Exposure to extremities may be higher.
PRIMARY CAUSE: Not stated (still under investigation)

DESCRIPTION OF ACCIDENT:

A Van de Graaff accelerator was being used for activation analysis. The exposure took place apparently as a result of the accelerator not shutting off after the irradiation of a sample of oil. The three men entered the target room, removed the sample, and then attempted to locate the source of trouble with the target cooling system. Possible explanations for the exposure appear to suggest the failure of the safety interlock system to shut off the accelerator and the lack of, or adherence to, proper operating and radiation safety procedures.

Ref: "Hearings before the Subcommittee on Public Health and Welfare of the Committee on Interstate and Foreign Commerce, House of Representatives, on H.R. 10790," Serial No. 90-11, statements of James G. Terrill, Jr., Director, National Center for Radiological Health, pp. 427, U.S. Government Printing Office.